Effect of liming on the change of some agrochemical soil properties in a long-term fertilization experiment

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ABSTRACT

For 10 years (1999–2008) there was investigated the effect of liming on soil pH_{KCl} and on organic carbon, available forms of macroelements and DTPA-extracted forms of some metals in 6 different fertilization objects in a long-term experiment set up in 1948: without fertilization (0), straw + NPK (STR NPK), NPK, farmyard manure (FYM), FYM NPK, FYM NPKMgCa. As a result of the application of 12.0 t/ha of lime (4.3 t Ca/ha), an increase was found not only in soil pH value but also in organic carbon, plant available phosphorus, zinc and copper contents and a decrease in manganese content. Despite significant changes in the soil properties, they still varied across the long-term fertilization objects.

Keywords: soil pH value; soil organic carbon; available macroelements; DTPA-extracted metals; field research

Globally a few hundred long-term experiments are being carried out. They are located in many countries, including Poland (Debreczeni and Körschens 2003, Blecharczyk et al. 2004). The aim of the experiments is to determine the effect of long-term exposition to natural and anthropogenic factors on the ecosystems or their components. Long-term experiments are also a very valuable scientific method in agriculture (Körschens 2006).

Fertilization is one of the main yield-forming factors. When applied properly, it helps maintaining or increasing the fertility and productivity of soil in a way that would be environment-friendly. When used improperly, especially for long time, it results in unfavourable changes in soil properties and other agroecosystem components, decreases the productivity of plants and deteriorates the yield quality (Edmeades 2003, Gamzikov et al. 2007). Long-term experiments point to a complex of direct and indirect changes in physicochemical and biological soil properties affected by the application of organic and mineral fertilizers or no fertilizers at all. Fertilization affects soil properties essential for its agricultural quality and ecological balance: the content and transformations of organic carbon (Kubát et al. 2006), acidification and soil reaction (Debreczeni and Kismanyoky 2005), nutrients contents as well as their availability to plants (Madaras and Lipavský 2009). The main reasons of unfavourable changes in soil and other components of agroecosystems are a lack or low organic fertilization, nutrients-unbalanced mineral fertilization, high doses of nitrogen, skipping liming, unbalanced fertilizer doses as compared with the plant fertilization needs. As a result, the following effects are observed: a decrease of organic carbon content, strong acidification, changes of total and available nutrients contents, deterioration in physical and biological soil properties. The changes are sometimes so strong that they lead to soil degradation and productivity loss (Pernes-Debuyser and Tessier 2004).

Liming is a common practice used to improve soil properties. It has both direct and indirect effect on: soil acidity, mobilization of plant nutrients and toxic heavy metals, soil aggregates and structure, biological activities (Tyler and Olsson 2001, Bolan et al. 2003).

The aim of the present research was to determine the effect of liming on soil pH value and organic carbon, available macroelements and DTPA-extracted metal contents, which strongly differentiated previous long-term fertilization.

MATERIAL AND METHODS

Field experiment. The research was performed over 1999–2008 in long-term fertilization experiment at Mochełek, in the vicinity of Bydgoszcz, Poland (53°12'24''N, 17°51'40''E, 98.5 m a.s.l.). The experiment was set up in 1948 on Albic Luvisol, in the region of low rainfall, 450 mm annually. For 53 years there were maintained, with slight modifications, 6 fertilization treatments in five replications in randomized block design: without fertilization (0); straw + mineral fertilization NPK (STR NPK); NPK (NPK), only farmyard manure once in crop rotation (FYM); FYM + NPK (FYM NPK); FYM + NPKMg + liming (FYM NPKMgCa). The fertilization rates were also undergoing some changes. Depending on the treatment and research years, the following doses were applied on average per year: 25–106 kg N/ha (ammonium sulphate), 19–46 kg P/ha (superphosphate), 19–120 kg K/ha (potassium chloride), 12–20 kg Mg/ha (magnesium sulphate), 110–640 kg Ca/ha. Farmyard manure (30–50 t/ha), straw (5 t/ha) and lime were used in respective experiment objects, every 4–6 years.

Due to a strong soil acidification over 2000–2008, fertilization was changed. In all the so-far-existing objects only mineral fertilizers were applied: 100 kg N/ha/year, 26 kg P/ha/year, 75 kg K/ha/year. In this period also liming was made three times in all objects. Total dose of lime used was 12.0 t/ha (4.3 t Ca/ha).

Soil sampling and analysis. In 1999 before and then after liming in 2008 soil was sampled from the layer (0–25 cm) from each fertilization object. The soil samples were air-dried, crushed and, after homogenisation, passed through a 2-mm mesh screen. The following were determined: the soil pH value, organic carbon and the content of plant available macroelements. Soil pH value in 1 mol/L KCl was determined in 1:2.5 soil:solution suspension using the pH-meter Schott Gerate CG 840 (Hofheim, Germany). The organic carbon content was recorded using Vario MAX CN – Elementar (Hanau, Germany). Chemical extraction for available phosphorus and potassium forms was made using the Egner-Riehm method (Egner et al. 1960). For the extraction, hydrochloric acid/DL solution was used (pH 3.6, 0.02 mol/L hydrochloric acid and 0.04 mol/L calcium lactate, soil:solution ratio 1:50). The availability of magnesium was determined by extracting the soil with 0.025 mol/L $CaCl_2$ (soil:solution ratio 1:10) according to the Schachtschabel method. Phosphorus was determined with the spectrophotometer Genesis 6 (Madison, USA), potassium and magnesium – using atomic absorption spectrometry (AAS, Philips 9100, Cambridge, UK).

In soil sampled in 2008 the DTPA-extracted metals contents were noted. The available zinc, copper, manganese and iron were determined by extracting the soil with 0.005 mol/L DTPA (pH 7.3, soil:solution ratio 1:2). The method described by Lindsay and Norvell (1978) was applied. The DTPA-extractable metals contents in soil were determined by atomic absorption spectrometry.

Data analysis. Soil pH values from all fertilization objects (not normal distribution) were compared before (1999) and after (2008) liming. The DTPA-extracted metals contents (2008) were compared with the earlier results from this experiment reported by Dąbkowska-Naskręt et al. (1999). The significance of differences in contents of organic carbon and available forms of phosphorus, potassium, magnesium at respective determination dates (1999, 2008) before and after liming were evaluated with the analysis of variance ANOVA (Statistica 7.0 StatSoft Inc, Tulsa, USA) and the Tukey's test (at the significance level P = 0.05).

RESULTS AND DISCUSSION

After about 50 years of Albic Luvisol fertilizing, there was recorded a strong differentiation in pH value and the organic carbon, available macroelements, and DTPA-extracted metals contents. Large changes in agrochemical soil properties, including pH value and the organic carbon, available phosphorus, potassium, magnesium, microelements, and contents are reported also in other long-term fertilization experiments (Ellmer and Baumecker 2005, Merbach and Deubel 2008).

Only a long-term regular combined application of organic and mineral fertilizers together with liming once in crop rotation – FYM NPKMgCa made it possible to keep the soil pH value at the level of 5.7. As for the other objects, soil in 1999 was strongly acid. The lowest pH value (3.4) was

Table 1. Soil pH_{KCl} and DTPA-extractable metals contents (mg/kg soil) before (1999) and after liming (2008) in a long-term fertilization experiment

Soil property	Year	Fertilization treatment					
		0	STR NPK	NPK	FYM	FYM NPK	FYM NPKMgCa
pH_{KCl}	1999*	4.2	3.6	3.7	3.6	3.4	5.7
	2008**	6.6	6.3	6.0	6.1	5.8	7.4
Zn_{DTPA}	1999	0.72	0.60	0.57	0.80	0.78	0.76
	2008	0.79	0.59	0.69	0.81	0.78	1.07
Cu_{DTPA}	1999	0.22	0.13	0.18	0.20	0.11	0.07
	2008	0.41	0.37	0.47	0.39	0.45	0.51
Mn_{DTPA}	1999	31.0	51.5	40.4	24.2	46.6	9.8
	2008	3.44	3.02	3.27	4.29	4.03	4.13
Fe_{DTPA}	1999	47.5	76.9	80.9	58.3	83.1	20.9
	2008	18.4	21.0	24.8	21.8	35.7	16.9

*DTPA-extractable metals contents according to Dąbkowska-Naskręt et al. (1999); **results of own study. 0 – without fertilization; STR NPK – straw + NPK; FYM – farmyard manure

reported for the FYM NPK fertilization treatment (Table 1). The results of long-term experiments in many countries of the world show that regular application of farmyard manure limits soil acidification and intensive mineral fertilization; especially with nitrogen and potassium, it results in a decrease in pH value, and even in soil degradation (Gomonova et al. 2007, Shahid et al. 2013). This long-term experiment at Mochełek (Poland) shows that the use of FYM only once in crop rotation, on average every 5 years, on light soil with a relatively low organic matter content and a lack of liming did not limit the acidifying effect of mineral fertilization. Only regular application of lime resulted in a successive, 1999 through 2008, increase in soil pH value in all fertilization treatments by 1.7–2.7 units. Soil pH value increased at least in the case of object earlier fertilized with FYM NPKMgCa, where it was the highest in 1999; this could have been due to the highest organic carbon content in soil in that object.

Liming changed the DTPA-extracted metals contents in soil, being microelements for plants. The zinc and copper contents changed less, while iron and manganese more (Table 1). In 2008, after liming, the DTPA-extractable zinc content in STR NPK, FYM and FYM NPK objects was similar to the one observed earlier by Dąbkowska-Naskręt et al. (1999).

The greatest difference in the Zn_{DTPA} content, an increase by 0.31 mg/kg soil, occurred in the object, where FYM with NPKMgCa was applied till 1999. In 2008, the zinc content in FYM and FYM NPKMgCa objects was more than 0.8 mg/kg soil. As a result of liming, the Cu_{DTPA} content increased in all treatments. Liming resulted also in a strong decrease in the content of DTPA extractable forms of iron and manganese, which are particularly dependent on changes in soil reaction, because the level of bioavailable forms of many metals is negatively correlated with pH value (Takáč et al. 2009).

In 1999 the highest soil organic carbon content was noted in the case of the objects where FYM and mineral fertilizers were applied for many years at the same time (Figure 1a). This confirms a favourable effect of organic with mineral fertilization on the soil organic carbon (Bhattacharyya et al. 2010). After liming the soil organic carbon content increased in all the objects, despite the fact that intensive liming can decrease its amount (Rogasik et al. 2004).

In 2008 it was still the greatest in the object earlier fertilized in a balanced way with FYM together with mineral fertilizers and periodically limed. This confirms that the method of fertilization helps to maintain or increase the soil organic carbon content under various habitat and agricultural conditions, which is seen from the results of long-term experiments carried out in Poland (Rutkowska et al. 2004) and other countries of the world (Manna et al. 2006).

A long-term lack of any fertilization and mineral fertilization resulted in a significant decrease in its available forms content in soil, in 1999 (Figure 1b). After liming, in 2008 the available phosphorus

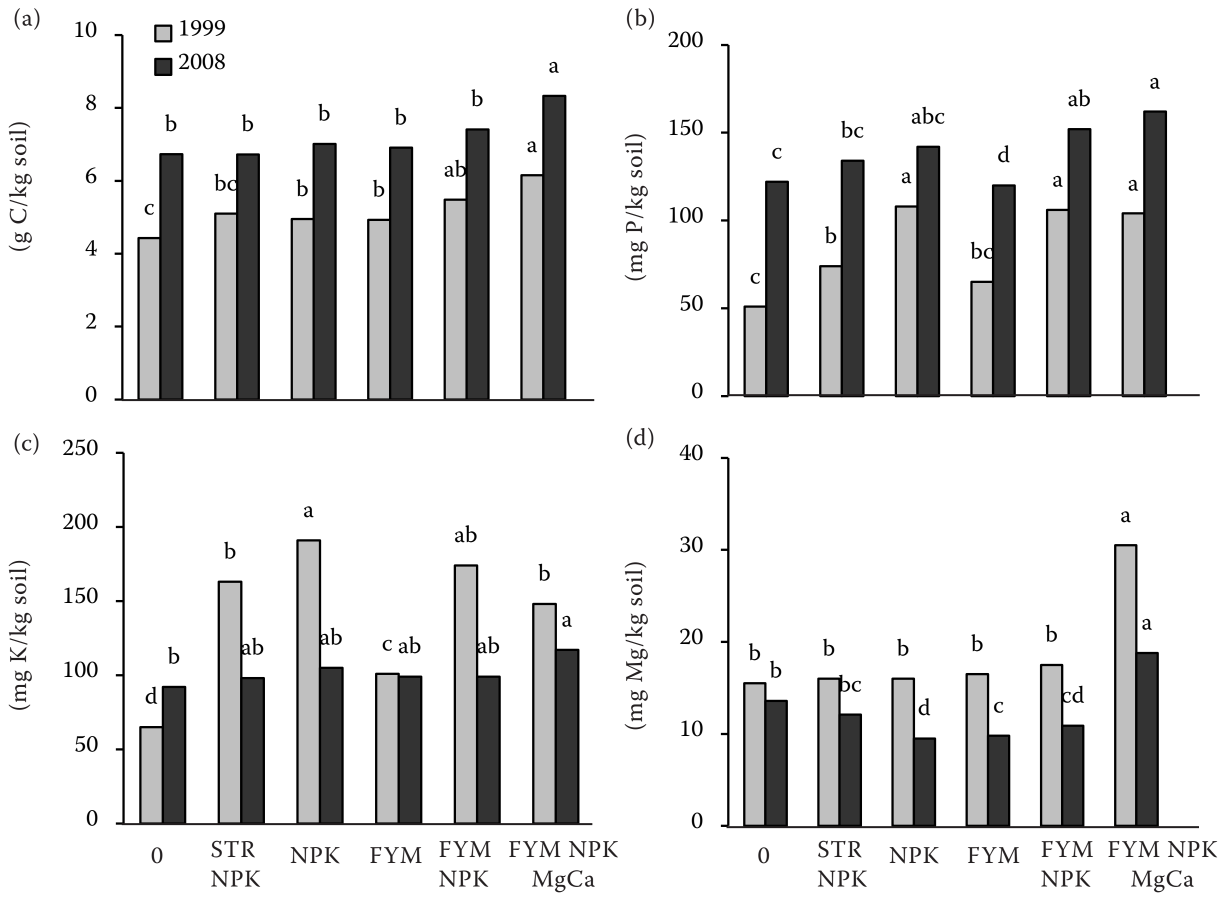

Figure 1. (a) Soil organic carbon; (b) available phosphorus; (c) available potassium, and (d) available magnesium content before (1999) and after liming (2008) in a long-term fertilization experiment. 0 – without fertilization; STR NPK – straw + NPK; FYM – farmyard manure

content increased in all the objects. The greatest increase, by more than 50 mg P/kg soil, was recorded for the no-fertilization treatment and treatments: STR NPK, FYM and FYM with NPKMgCa. An increase in the available phosphorus content in strongly acidic soil after liming was also recorded in other experiments (Özenç and Özenç 2009). Such changes can occur even already after a single lime application (Szymańska et al. 2008).

After intensive liming, the available potassium and magnesium contents in soil decreased (Figures 1c, d). Curtin and Smillie (1986) demonstrated in a laboratory experiment that liming decreased those macroelements content in soil solution. In field experiments the relationships are not so clear-cut. In the present research it was found that in the long-term no-fertilized object where 75 kg K/ha/year and lime were applied in 1999–2008, the available potassium content increased. The greatest magnesium losses occurred in the object where soil was fertilized with that nutrient – FYM NPKMgCa in the long-term experiment. After stopped its application and liming stopped in 1999, despite an increase in soil pH, the magnesium content in that object decreased by about 12 mg Mg/kg soil.

On the basis of these results it can be said that liming is a treatment which enhances unfavourable agrochemical soil properties, mostly strongly acidic reaction, developed by long-term unbalanced fertilization. Regular application of lime in 10 years resulted in an increase of pH value as well as organic carbon, plant available phosphorus, zinc and copper contents. During this period potassium (with the exception of the object 0), iron and, in particular, manganese content decreased. Despite significant changes in the agrochemical soil properties as a result of liming, they still varied across the long-term fertilization objects.

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